MINIMIZATION OF SCOUR DEPTH DOWNSTREAM RADIAL STILLING BASINS

Abdelazim M. Negm

Professor of Hydraulics, Dept. of Water & Water Structures Eng.,
Faculty of Engineering, Zagazig University, Zagazig, Egypt,
E-mail: **amnegm85@yahoo.com**

ABSTRACT

In this research paper, the effect of the position of central symmetric sill on the maximum scour depth downstream (DS) of radial stilling basin (RSB) was investigated experimentally. Central symmetric sill of particular length (normal to the flow direction) were tested at different positions with reference to the position of the control gate. The flow pattern was observed and the scour pattern was measured for each test. The optimal position of the central symmetric sill that minimizes the maximum depth of scour DS. radial stilling basin based on the analysis of the experimental measurements. Results were compared to the no sill case. It was obtained that the scour is minimized if the sill is installed within the middle third of the basin. The effect of using an end sill combined with the central sill at the optimal position was also investigated. It was found that the scour process were slightly reduced (in each of the three dimensions) when the central sill at the optimal position was combined with the end sill. A prediction model was developed using the multiple linear regression analysis to estimate the maximum scour depth. The other characteristics of the scour and deposition process were also presented and discussed.

Keywords: Scour, Stilling basins, hydraulics, hydraulic structures, erosion

INTRODUCTION

Radial stilling basins with or without sills could be used effectively in dissipating the excessive energy DS of hydraulic structures. The effect of sill on the flow and/or scour characteristics depends upon the configuration of the sill, its geometry and the flow regime.The effect of baffle sills over rigid and erodible beds was investigated by Smitth and Yu [6]. Abouel-Atta [1] investigated the phenomenon of local scour downstream radial stilling basin, under the effect of floor reversed jets. The floor jets reduced the scour depth, length to maximum scour and the volume of scour. Formulae to predict the scour depth as a function of time and Froude number were developed. Other investigations of related interest but in sudden expanding stilling basins were shortly reviewed in Negm [4]. The present research paper concentrates on the effect of the position of the central sill in radial stilling basin on scour characteristics downstream of the basin including the maximum depth of scour, the length to the maximum scour, the flow and scour patterns.

THEORETICAL ANALYSIS

Figure 1 shows a definition sketch for the phenomenon being investigated. Considering the maximum scour depth, D_s, downstream the radial stilling basins as dependent variable, the following functional relationship can be expressed as follows:

$$D_S = f(g, \rho, \rho_s, G, V_G, b, B, H_u, D_{50}, X_s, L) \tag{1}$$

in which g is the gravitational acceleration, ρ is the density of water, ρ_S is the density of the movable soil, G is the gate opening, V_G is the mean velocity under the gate, b is the approaching channel width, B is the width of the expanding channel, H_u is the upstream water depth, D_{50} is mean particle diamter, h_s is the height of the sill, X_s is the position of the sill from the expanding section and L is the length of the basin.

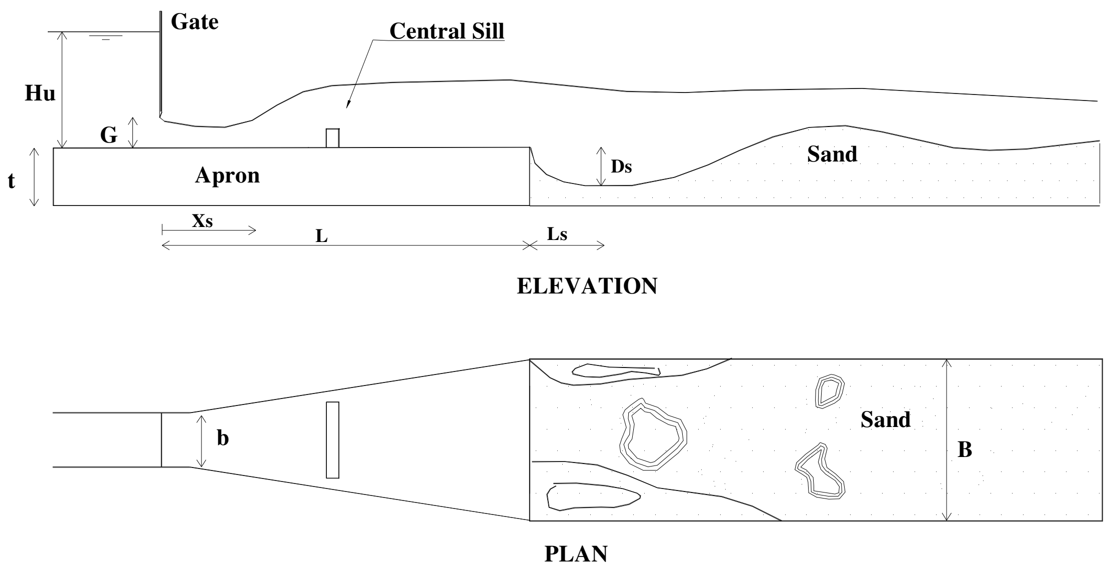


Figure 1. Definition sketch for a test model arrangement in radial stilling basin

Applying the Π theorem with ρ, G, V_G as repeating variables, equation (1) can be written in dimensionless form as follows:

$$\frac{D_s}{G} = f\left(F_G, \frac{H_u}{G}, \frac{B}{G}, \frac{b}{G}, \frac{D_{50}}{G}, \frac{L}{G}, \frac{\rho_s}{\rho}, \frac{X}{G}\right) \tag{2}$$

In which $F_G = V_G /(gG)^{0.5}$ is the Froude number under the gate. The effects of B/G, b/G, D_{50}/G, L/G and ρ_s / ρ were excluded because only one fluid and one soil were used during the course of experiments. The widths of the narrower and wider channels as well as the apron length of the basin were kept constant.Hence; equation (2) is reduced to

$$\frac{D_s}{G} = f\left(F_G, \frac{H_u}{G}, \frac{X_s}{G}\right) \qquad (3)$$

EXPERIMENTAL ARRANGEMENT

The experiments were conducted in a recirculating laboratory flume 0.20 m wide, 0.25 m deep and 3.5 m long. The discharges were measured using a pre-calibrated orifice meter installed in the feeding pipeline. The stilling basin model was made from prespex of thickness 10 mm with a length of 1.25 m. The length of the approaching channel was 50 cm while the length of the apron of the radial stilling basin is 75 cm. The width of the approaching channel was kept constant to 13 cm, and the width of expanding channel was fixed to obtain an expansion ratio of 1.54, which was close to the one normally used in practice. The diveregence angle was kept constant to 5.34^o.

A control sluice gate was made from the same prespex and was used to control the upstream depth and the gate opening. The gate was installed 5 cm upstream the sudden expansion section. The rest of the flume (2.5 m) is covered by sediment consisting of 7.5 cm sand layer of medium diameter, D_{50} = 1.77 mm. The tailgate at the end of the flume was used to control the tail water depth. During the course of the experiments, the tailgate was controlled such that the tailwater depth was about 5 cm.

Five models were tested. One model was consisted of smooth RSB (no sill case). A central sill of height 1.5 cm, 0.8 cm wide and 14 cm long was fixed in the RSB. Different positions of sills viz. 0.2L, 0.4L, 0.6L and 0.8L were tested. The position that yields minimum scour was tested in combination with end sill that having 2:1 US slope and vertical DS face with a height of 1.5 cm. The selection of the models was based on results of previous researches conducted by the Bremen and Hager [3] and Negm [4].

Range of discharges and gate openings were used such that the Froude number under the gate ranged from 1.50 to about 4.5. A total of about 36 runs were performed. The time of each run was chosen to be 45 min based on previous studies, Negm [4]. A typical run consisting of leveling the movable soil, allowing a particular fixed tailwater depth in the downstream channel with the control gate in close position. The discharge was adjusted to the desired value and the gate was opened to the desired opening to obtain the required under gate Froude number. During each run the flow pattern was observed and sketched. The deflection of the supercritical jet was recorded. After about 20 minutes, the water surface profile was recorded and its direction was noticed. After 45 minutes, the control gate was closed and the pump was switched off. The topography of the movable bed was measured at each 5 cm in the direction of the flow (x direction) and in the widthwise direction or lateral direction (y direction) to enable the study of the scour pattern.

RESULTS AND DISCUSSION

1. Relative Maximum Depth of Scour

Figure 2a presents the relationship between D_s/G and F_G for all the conducted experiments. It is observed that the relative scour depth is high for high Froude number and vice versa for almost all cases with a linear increasing trend. Figure 2a indicated that the presence of central sill in RSB reduced the depth of scour significantly compared to the case of no sill. These results corporates well with those obtained by Ali [2] in rectangular basins, Smith and Yu [6] and Negm [4] in expanding basins. Furthomore, at particular Froude number, the vertical variation in the relative scour depth was due to the effect of position of the sill. The position of the sill has a remarkable effect on reducing the magintude of the scour depth DS of RSB. It is observed that the sill at the position 0.4L produced the minimum relative depth of scour, D_s/G followed by the sill at 0.2L. Cobining the central sill at 0.2L with the end sill slightly reduced the magnitude of the relative maximum depth of scour but less than that produced by the sill at the position 0.4L. This proves that the use of end sill had not a significant merit over the central sill when used in RSB, which matched well with prevous investigation on the effect of end sill in sudden expanding stilling basins, Saleh et al. [4]. They proved that the end sill was not recommended for scour reduction DS of expanding stilling basins. It is interesting to observe that the sill at the position 0.6L reduces the scour depth more than that at 0.8L but more than the sill at 0.4L.

2. Relative Length to the Maximum Scour

On the other hand, Figure 2b presents the relationship between L_s/G and the F_G for the same sills presented in Figure 2a. The nature of the relationship between L_s/G and F_G follows the same trend of variation as that shown in Figure 2a. Clearly, the presence of sill in the RSB reduced the length to the maximum scour depth over the erodible bed DS of RSB. The length to the maximum scour was longer in case of no sill compared to when the sill was used regardless of it position in the basin. However, the sills at positions 0.2L and 0.4L were equally attracted when F_G was higher than 3.0 with preference to the sill at the position 0.4L for all ranges as it produced lower values of both D_s/G and L_s/G at almost all F_G. The end sill had no remarkable effect on scour processes as discussed above. Its line in Figure 2b was very close to that of the sill at 0.4L (but above those below 0.2L).

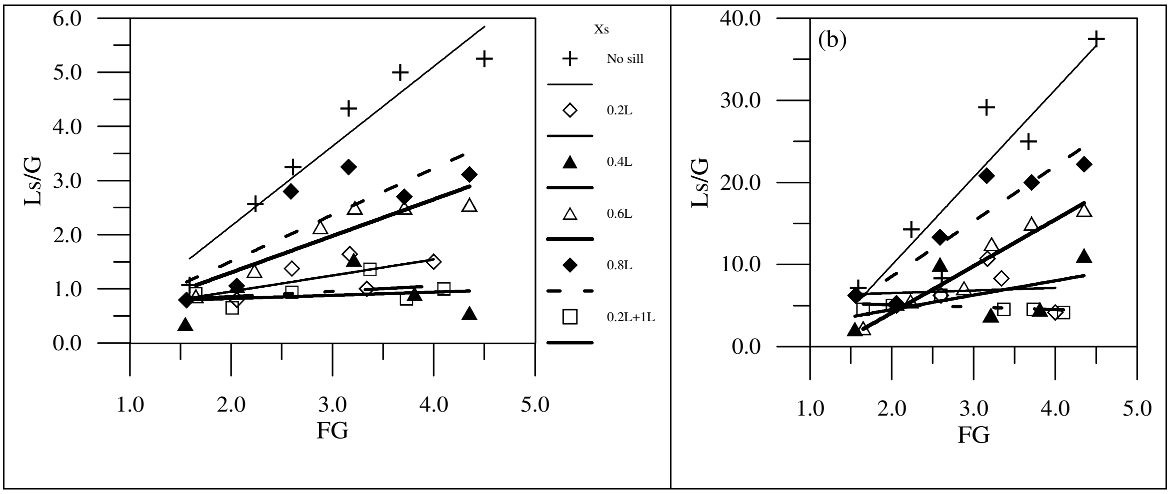


Figure 2. The Relationship between (a) Ds/G and F_G and (b) Ls/G and F_G for different positions of sill

3. Water Surface Profile

Typical water surface profiles for no sill case and for the sill at position 0.2L at F_G=2.6 are shown in Figures 3a, b. Inspection of these figures and others (not plotted to reserve space) indicated that the water surface profile in no sill case was rough and fluctuating. A weak hydraulic jump was formed changing the flow from supercritical flow near and under the gate to subcritical flow near to the end of the basin and over the erodible bed. The water surface of the main jet of flow was slightly different from the water surface through the centerline of the flume leading to asymmertic flow patter inside the basin. The presence of sill forces the water to form a jet near the sill but the water surface DS the sill became smoother than for the no sill case. Moving the sill from the position 0.2L towards the end of the basin 0.8L, the water surface changes from smooth to slightly rough but still smoother than the no sill case leading to more dissipated energy and hence lower values of scour DS of RSB.

4. Flow and Scour Patterns

The flow pattern for the no sill (as shown Fig. 4a) shows that the main jet of flow was deflected towards one of the basin sides and then flows in the same direction parallel to the center line of the basin (asymmetric flow). When the main jet reached the erodible bed, as shown in Figure 4b, a scour hole forms at the same side and a mound was formed on the other side. Part of the flow in the scour hole carried some of the soil particles back to the apron of the stilling basin. This means that the asymmetric flow pattern in the diverging stilling basin without sill caused asymmetric scour pattern. It was also observed that the length of scour and deposition process equals 1.53L for a typical value of F_G =2.6. It might reache a maximum of 2.66L for F_G=3.16. On the other hand, the minimum length of scouring and deposition process for the case of no sill was about 0.4L for F_G=1.59.

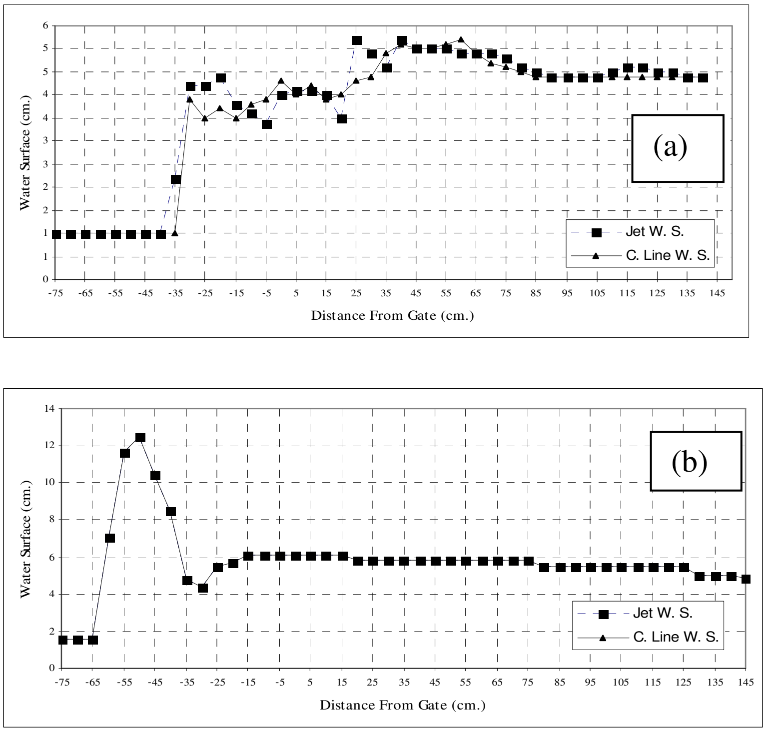
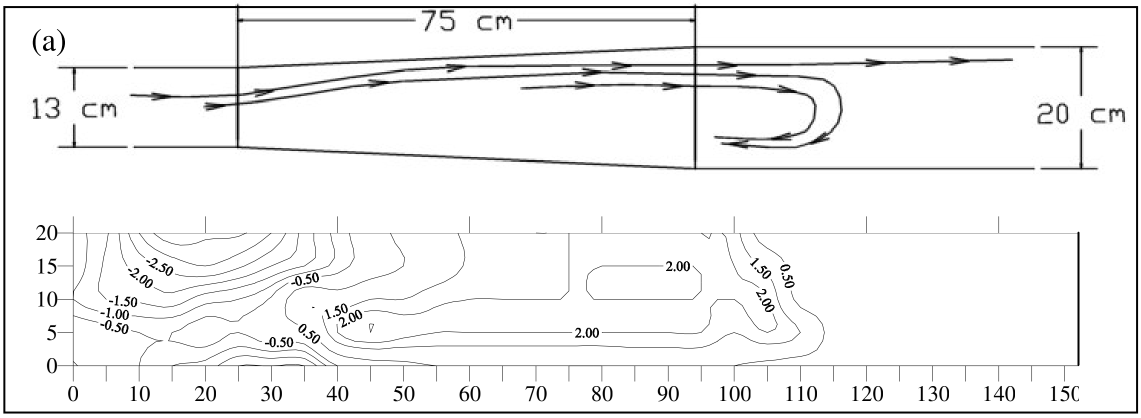


Figure 3. Typical water surface profile for (a) no sill case and (b) sill at 0.2L, when F_G=2.6 and e=1.54



(b)

Figure 4 Flow and scour patterns for no sill case at F_G=2.61

When the sill was used the lengths of the scouring and deposition were siginficantly reduced as shown in Figures 5, 6 and 7 as typical examples. It was observed from Figure 5a where the sill was located at 0.2L, the main jet of flow was deflected towards one of the flume side resulting in asymmetric flow. But, as shown in Figure 6a when the sill was located at 0.4L, the main jet of flow was nearly symmetry for the same value of Froude number (F_G=2.6). Regarding the sill positions 0.6L and 0.8L, the main jet of flow in both cases was deflected towards one of the basin sides as shown in Figures 7a for 0.6L. Combining an end sill with the sill at the position 0.2L yields flow pattern similar to that produced by the sill at position 0.4L (Fig.6a). By inspecting the above figures and all the plotted flow and scour patterns, the following observations could be stated regarding the scouring and deposition processes.

- As shown in Figure 5b, the main scour hole occurs at the same side of the jet yielding asymmetric scour and the length of scour and deposition process equals about 0.86L at F_G=2.6 when the sill was located at 0.2L with a maximum of 1.3L at F_G=2.056 to a minimum of 0.47L at F_G=4.0

- When the sill was located at 0.4L the formed main scour hole was symmetric around the centerline of the flume as a result of the symmetric flow in the RSB (Fig. 6b). In this case, the length of scour and deposition processes ranged between 0.3L at F_G=4.35 to L for F_G=2.59.

- When the sill was positioned at 0.6L or 0.8L, the main scour hole occurs at the same side of the jet and the length of scour and deposition process ranged between 0.75L to 1.1L for the first position (Fig. 7b) and about 0.75L to 1.7L for the second position within the experimental range.

- When the end sill was combined with the sill at 0.2L the main scour hole occurred symmetrical around the centerline of the flume and the length of scour and deposition process equals approximaltely about 0.9L at F_G =2.6 and ranged between 0.4L to 1.13L for the present experimental range.

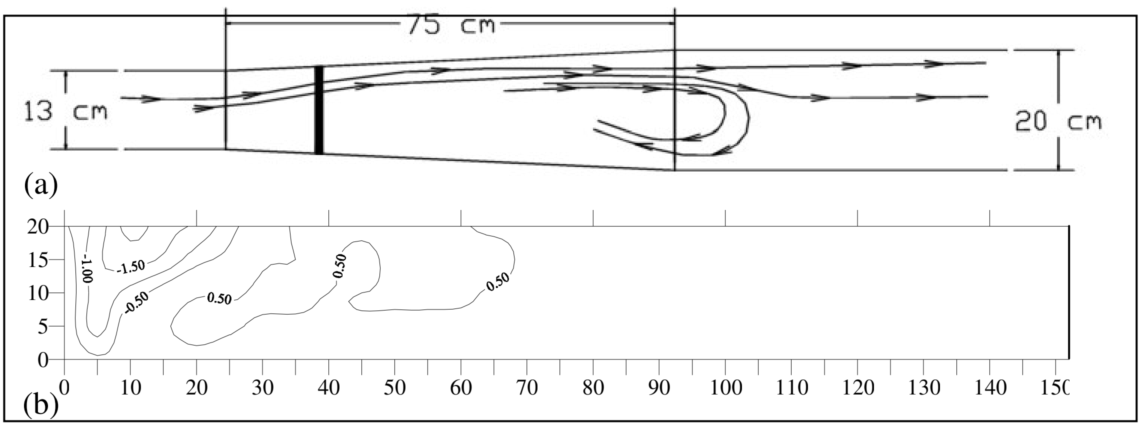


Figure 5 Flow and scour patterns for sill at position 0.2L and F_G=2.60

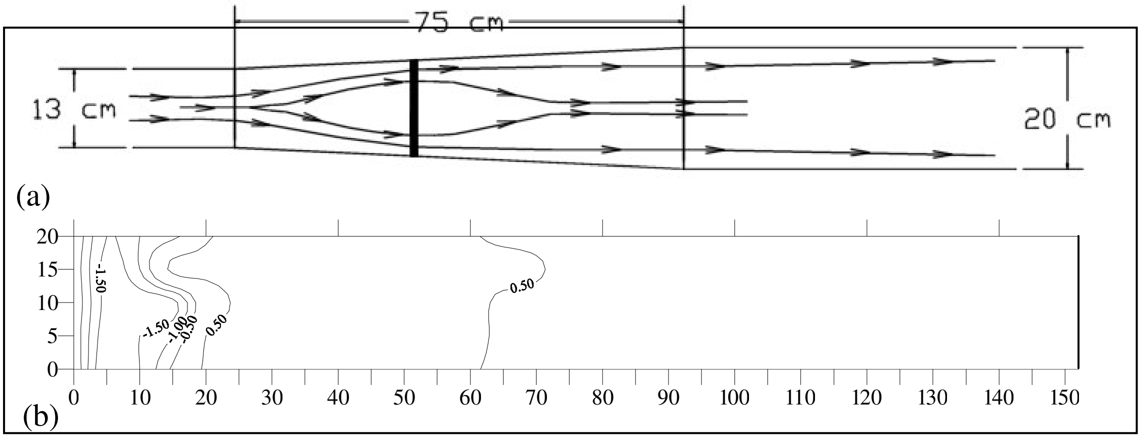


Figure 6 Flow and scour patterns for Sill position at 0.4L and F_G=2.59

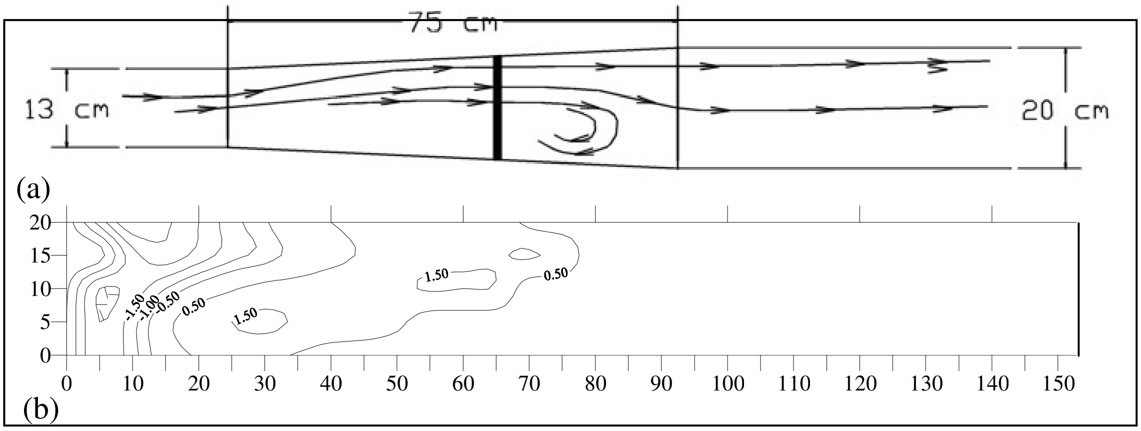


Figure 7 Flow and scour patterns for sill position at 0.6L and FG=2.6

ESTIMATION OF MAXIMUM SCOUR DEPTH RATIO DS/G

Using the multiple linear regression analysis, the following equation was found to represent the data well with R^2=0.707 (one point was exculded from the fitting and if it is included R^2 was reduced to to 0.572 with the following coefficients –1.136, 0.039, -0.122 and 1.444).

$$\frac{D_s}{G} = -1.0423 + 0.0412\frac{X_s}{G} - 0.1026\frac{H}{G} + 1.2282F_G \qquad (4)$$

The estimated values of D_s/G from equation (4) are plotted against the measured ones as shown in Figure 8. It was observed that fair agreement between the estimated values and the measured was obtained.

For no sill case, the following equation could be used to estimate the maximum scour depth DS of RSB (R^2 =0.922).

$$\frac{D_s}{G} = -0.786 + 1.4747F_G \qquad (5)$$

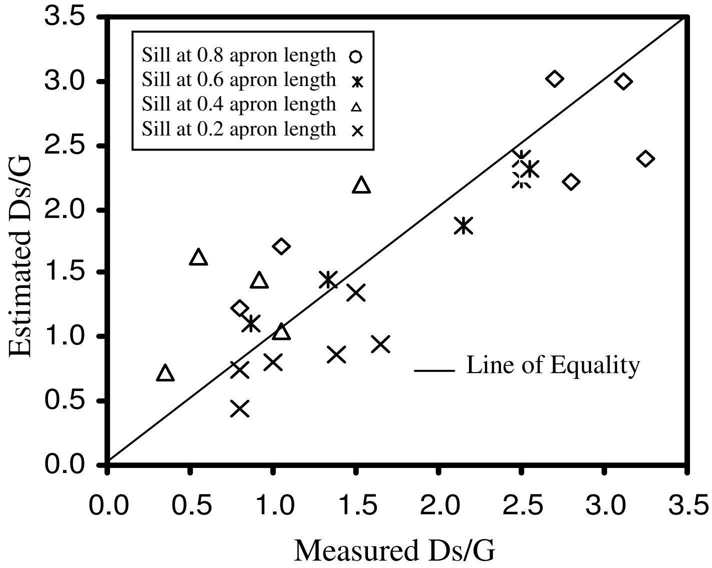


Figure 8 Comparison between estimated D_s/G and measured ones for RSB with floor sill.

The values of Ds/G for the combined case of end sill and the sill at the position 0.2L (although it is not highly recommended) could be rougly estimated using the following equation

$$\frac{D_s}{G} = 0.0974 F_G + 0.663 \quad (6)$$

CONCLUSIONS

An experimental investigation was conducted to study the effect of the position of the central sill in the radial stilling basin on the scour downstream of the basin. The following conclusions are highlighted:

1. Generally, the scour pattern is not symmetrical and the maximum scour occurs either on the left or on the right from the longitudinal center line of the channel DS of RSB.
2. The relative scour depth is high at high values of Froude number and vice versa for most of the tested models with or without sill.
3. The presence of central sill reduces the maximum depth of scour and the rate of reduction depends upon the position of the sill.
4. The sill located at 0.4L from the gate produces the lowest depth of the scour DS of RSB and a relatively short length to the maximum scour. Also, it yields symmetrical both flow pattern inside the basin and symmetric scour pattern DS of the basin.
5. The flow is being asymmetric at any other of the tested positions except when the sill at 0.2L is combined with the end sill, a symmetric flow

pattern is observed and the scour is also reduced compared to when the sill is at 0.2L only.

6. The position 0.6L is better than that at 0.8L in reducing the maximum depth of scour, although the flow and scour patterns are almost similar and symmetric.
7. Equations were developed to estimate the maximum scour depth DS of RSB with or without central sill respectively.

REFERENCES

[1] Abouel-Atta, N. 1995. Scour prevention using a floor jets mechanism. Civil Engineering Research Magazine, Faculty of Engineering, Al-Azhar University. Vol. 17, No. 2, February, pp. 256-268.

[2] Ali, N. A. 1955. The proper location of Floor sill with scour reach downstream of heading-up structure., Bulletin of the Faculty of Engineering, Assuit University, Vol. 23, No. 2, July, pp. 11-18.

[3] Bremen, R.& Hager, W.H. 1994, "Expanding Stilling Basin." Proc. Instn Civ. Engrs Wat., Marit. & Energy, Vol. 106, No. 9, pp. 215-228.

[4] Negm, A.M. 2004. Effect of sill arrangement on maximum scour depth DS of abruptly enlarged stilling basins. Proc. of Int. Conf. Hydraulics of Dams and River Hydraulics, 26-28 April 2004, Tehran, Iran.

[5] Saleh, O.K., Negm, A.M., Waheed-Eldin, O.S. and Ahmad, N.G. 2003. Effect of End Sill on Scour Characteristics Downstream of Sudden Expanding Stilling Basins. Proc. of 6th Int. River Engineering Conf. Published on CD ROM and Booklet of Abstracts, Ahvaz, Iran, 28-30 Jan.

[6] Smith, C. D. & Yu, N. G. 1996. Use of Baffles in Open Channels Expansion. Journal of The Hydraulic Div., ASCE, HY2, March, pp. 1-17.

NOTATIONS

b	The width of approaching channel.
B	The width of wider channel.
D_s	The max. scour depth.
D_{50}	The mean particle diameter.
e	The expansion ratio.
F_G	The Froude number under the gate.
G	The gate opening.
g	The acceleration due to gravity.
H_U	The upstream water depth.
h_S	The sill height.
L	The length of apron.
L_S	The length of the max. scour depth from the apron.
V_G	The mean velocity under the gate.
X_S	The distance of sill from expansion section.
ρ	The water density.
ρ_S	The density of the movable soil.